Alexandra Evders

R-1074

PROGRESS REPORT: A RESEARCH PROGRAM FOR THE PHYSICALLY HANDICAPPED TO DEVELOP INDEPENDENCE VIA "BUILD-IT-YOURSELF" KITS AND PRACTICAL INSTRUCTION IN ENGINEERING TECHNOLOGY

by

Richard E. Warren

April 1977

Center for Advanced Rehabilitation Engineering
THE CHARLES STARK DRAPER LABORATORY, INC.
CAMBRIDGE, MASS. 02139

in cooperation with:
COTTING SCHOOL FOR HANDICAPPED CHILDREN
BOSTON, MASS. 02215

The Charles Stark Draper Laboratory, Inc.
Cambridge, Massachusetts 02139

unbound booklet

Resource type (paperback book, hardback book, booklet, stapled booklet, ________

Publication year: 1977

Title: Is the title obvious? (you don't have to write it down if it is)

Author: Is the author obvious (ditto) If not, List main author(s) ____________________

Brief summary of the resource:
A book which describes the ~~engineering~~ philosophy ~~for designing~~ and goals ~~uses, and aspects~~ of engineering and designing assistive technology of ~~varieti~~ various varieties.

Rating (1-5 stars) How useful or interesting is this?

High rating: DIY things that you can build, diagrams, suggested uses, multiple languages, good descriptions

Low rating: An encyclopedia style thing that lists places you could buy a sock puller onner in 1965

Tags
assistive tech, DIY, diagrams, instructions, specifications, materials list,
communication boards, AAC, switches, electronics, video gaming
clothing, sewing, eating, cooking, utensils, grip, bathroom, bed, seating, standing frames
wheelchairs, wheelchair mods, lifts, ramps, canes, crutches, walkers, rollators,
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M. YOUNG

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Approved: ______________
W. R. Manlove

ABSTRACT:

This report summarizes 4 years of research in technical education for the handicapped. A ~~fundamental concern~~ of this program has been the ~~problems of high cost~~, ~~complexity~~, and ~~reliability of aids~~ for the physically handicapped. Central to this effort has been the ~~development of methods for teaching the handicapped how to be more self-sufficient in the design, assembly, and maintenance of their~~ own ~~aids~~. This was achieved in part through the development of a course in Practical Engineering for the Physically Handicapped to be taught at the high school level. Simple basic concepts in engineering are introduced along with hands-on experience in design and assembly using simple "do-it-yourself" kits intended both to illustrate engineering principles which help attract more of the handicapped to rehabilitation engineering as a vocation, and also to serve as practical and economical aids for the handicapped.

TABLE OF CONTENTS

I. INTRODUCTION

This document reports on work in progress and discusses some of the important philosophical issues underlying a research effort to explore alternative ways of promoting self-help among the physically handicapped.

This effort began with the perception that aids for the physically handicapped are often needlessly expensive and complicated. A major part of the expense is attributable to the labor costs of the highly trained specialists who assemble t [illegible] the handicapped could be made simpler and cheape [illegible] ble to a wider market, if somehow the hand [illegible] to become more involved in the design, buildin [illegible] eir own aids. This research was aimed at dev [illegible] his problem, which includes teaching the handicapped some simple basic concepts in engineering technology and providing them with simple devices, in kit form, which they can build and maintain themselves.

WRONG ↑ ASSUMPTION
LABOR COST IS NOT USUALLY A MAJOR FACTOR

In this approach, the designs are kept quite simple so that an average individual with a high school education can understand and deal with all the important mechanisms. Instead of investing a highly sophisticated technology in the devices alone, the sophistication is invested in the tools, materials, and instructional techniques that allow the handicapped to design and create their own aids.

It is worth noting that this approach involves research and development in two areas that are not normally linked together into a single program. One area is the design and instrumentation of hardware for simple build-it-yourself kits, along with the development of tools for the handicapped to construct these kits. The other area is the development of classroom materials, texts, and methods, making possible a course in practical engineering for the handicapped which

provides "hands-on" experience in the design and maintenance of aids for the handicapped.

This program was undertaken as a joint effort of the Charles Stark Draper Laboratory (CSDL) and the Cotting School for Handicapped Children (formerly known as the Industrial School for Crippled Children). Engineering and curriculum development, including classroom instruction, was carried on primarily by CSDL staff and thesis students from the Massachusetts Institute of Technology (MIT). Clinical evaluation and technical advising was performed by Cotting School staff. Over the past 4 years, 23 students from the Cotting School, ranging in age from 14 to 18 years, have participated in a series of experimental classes and workshops which have served as a testbed for this program.

II. BACKGROUND: THE PROBLEMS OF THE PHYSICALLY HANDICAPPED

Workers in the field do not need to be told that the physically handicapped have a low visibility in our culture. A layman is often surprised to learn that the number of physically handicapped individuals in the United States is greater than 1% of the total population. Although estimates vary, as one might expect given various definitions of "handicapped", with some estimates running as high as 15%, a conservative estimate is that approximately 3 to 4% of the population has some form of motor-control or mobility problem that limits their employability. This figure is exclusive of individuals with primarily perceptual problems and it does not count those of advanced age paralyzed, for example, by a recent thrombosis or myocardial infarction. This figure does include paraplegics, spastics, amputees, and the like, who have suffered either some neurological disease (e.g., cerebral palsy, muscular dystrophy) or a severe trauma (e.g., war wounds, automobile accidents) whose handicaps limit their vocational horizons in what otherwise would have been their most productive years, between 20 and 65 years of age.

The more conservative figure of 3% represents a population of about 6 million severely handicapped individuals in their early or middle years of life. This is a population one almost never hears about. Recent strides in affirmative action have improved the circumstances of a relatively small handicapped population, those in wheelchairs, through newly created federal building codes that require wheelchair ramps and restroom accessibility, but few are aware of the problems of nonwheelchair cases. For example, it is not widely appreciated that noise pollution - something as simple as a honking horn - can play havoc with a spastic with an uncontrollable startle reaction.

It is a mark of our culture's fixation upon the so-called "beautiful person" that the problems of the handicapped are almost never discussed openly. The result is that the problem-solvers of the world, the scientists and engineers with the proper technology and materials at their disposal, are often unaware or unfamiliar with the real problems of the handicapped.

Moreover, it can be argued that those few scientists and engineers, who do take up the challenge of investing their energies in solutions to problems for the handicapped, typically approach those solutions with a perspective that is somehow wrong, perhaps even systematically inappropriate. At least this is the view we have slowly arrived at after 3 years of evaluating devices and materials currently available to the handicapped community.

Engineers, almost unconsciously sometimes, strive for a design that in some sense "does everything", that offers one a world on a "silver platter". For example, if given the chance, engineers generally prefer to design a Cadillac rather than a Ford; the Cadillac is likely to incorporate more interesting gadgets. If it were possible for the Cadillac to serve breakfast in bed, the typical designer would at least be tempted to include that concept in his design. The result is that engineers tend to create devices which in some way insulate the user from the process he is performing, just as a Cadillac insulates the driver from the road more than a less expensive car.

In the case of the handicapped, this approach is precisely the opposite of what is wanted; the handicapped are already insulated from their world in too many respects. Ultimately, this kind of approach turns what might otherwise be a widely accessible technology into an elite science understood only by a few; it promotes dependence, high costs, and makes hidden mobility demands. In the end, it serves to

isolate the handicapped from a technology that they need most. The purchase price of a motorized wheelchair, for example, may be higher than an expensive sports car. Maintenance is even more expensive, since only a few are qualified to repair it. This means that the handicapped will probably travel some distance for maintenance and repairs. This seems like a poor solution for those whose mobility is already less than adequate. The successful consumers of an elite technology require a high degree of mobility.

III. PHILOSOPHICAL ISSUES

1. BASIC GOALS: Simplicity, Technical Competence, and Independence

a. Simplicity: An obvious solution to these problems is to promote the design and development of aids that insulate the handicapped less from the world by making them less dependent upon an elite technology. Devices that are simpler and easier to understand are devices whose maintenance does not make serious demands upon mobility. This does not necessarily mean that the user or consumer should always have to maintain his own device; simplicity of design merely increases the likelihood that someone close by, if not oneself then perhaps a neighbor or local repair shop, can do the required maintenance.

Mobility constraints are becoming increasingly important, not only for the handicapped, but for the world as a whole, especially as the world's energy resources continue to be depleted. This suggests a need to transform the way engineering is taught in educational institutions so that the delivery of engineering technology to the community is more in keeping with the mobility and energy constraints on that community.

b. Technical competence: Another solution is to make engineering technology available to a wider audience. Engineering would be less likely to become an elite technology if it were to become part of a normal high school education. Traditionally, high school students have been exposed to science rather than technology. Although a few high schools have experimented with engineering courses, at present engineering technology is not one of the disciplines normally available in secondary education. Some high school administrators have expressed a concern that teaching engineering at the high school level would require an enormous facility because there are so many different

forms of engineering (e.g., mechanical, electrical, aeronautical, civil, etc). Our experience, conducting classes covering a general introduction to the engineering sciences as part of the MIT freshman seminar program, is that there is a wide set of perspectives and methodologies common to all the engineering sciences that could be taught at the secondary level. Indeed, if more high school students had had some exposure to the engineering sciences, they would be better able to decide upon an engineering major without the usual general introductory course in their freshman year, which MIT and other technical schools across the country have been forced to include in their course catalogues.

At a time when technology promises to solve many of the problems of our age, everyone can benefit from more education in engineering and technology; however the handicapped community stands to gain even more by training its members to become engineers and technicians. Such training allows them to assume decision-making positions and to control the delivery of a technology that vitally concerns them, which, until now, has been left largely in the hands of the nonhandicapped.

c. Independence: The goal of every handicapped individual is independence and the freedom to participate in the world at all levels, in short, to control his own destiny. This means independence in economic terms as well as psychological terms. The less an individual has to rely upon others for simple everyday tasks, the more productive that individual becomes in his community. The physically handicapped represent an enormous untapped labor resource. Many spend their whole lives at home idle. This resource has been difficult to tap in a systematic way because one individual's handicap is so different from that of another. Our approach to this problem is to

teach each individual how to specify his own "kit" and to do his own custom fitting. This need not demand a great deal of expertise. Almost any device or aid for the handicapped that promotes independence, however inefficient by ordinary standards, is bound to represent an increase in total economic productivity. A special tool, like a soldering iron or a wrench, that a spastic could use to design and build his own aids, is bound to result in some increase in productivity, especially if the alternative is remaining idle at home.

2. TRADEOFFS: Reliability, Maintainability, and Labor Costs

The fundamental problem of reliability is that perfection is unattainable, and anything less is dangerous, at least for unsophisticated users. No matter how sophisticated the design, everything breaks down eventually. A breakdown in a system that is advertised to be highly reliable and maintenance-free will always come as a surprise and catch the user off guard. Therein lies the danger. Yet the quest for the unattainable goes on, apparently with the blessing of both design engineers and consumers.

It has been said that engineering is as much an art as it is a science; I doubt that the full depths of this observation have been widely appreciated by nontechnical audiences. Engineering is not simply the practice of applying a theory or a series of equations to the solution of a given problem. As in the field of medicine, or any applied science, the engineer, first as a student, then later as a practitioner, forms a set of values which is not strictly quantifiable, nor even in some contexts rational. These values are the result of a slow evolutionary process, a kind of cultural development, based upon the accumulated experience of many years of many individuals practicing the "art" of engineering.

These values may play a more important role in determining the design of a particular device than do the theories, equations, and apparent tools of the trade. The possibility that present engineering practices are somehow systematically inappropriate for the handicapped makes it important to examine some of these values more explicitly than one might otherwise think necessary in an ordinary engineering program.

Among engineers, at least in this country, reliability has an unquestioned stature in the hierarchy of design values. There is a kind of tacit assumption that the consumers of today's technology are not smart enough to fix or maintain anything. This assumption may indeed be appropriate for the population as a whole; however, it need not be equally valid for selected subgroups of that population. An uncritical acceptance of this assumption, and its corollary that the great mass of people is probably uneducatable and intransigent, understandably encourages engineers to design devices which require infrequent maintenance and that are failure proof within some specifiable and predictable lifetime. As a result, the products of our technology fall into one of two extreme categories. Either devices have a long trouble-free life expectancy, are relatively sophisticated and therefore expensive to buy and costly to maintain when failures do occur (everything fails eventually), or else they are relatively cheap but have short expected lifetimes, requiring no maintenance and making use of throwaway materials like Teflon self-lubricating bearings. In either case, ease of maintenance is sacrificed in the interest of reliability. This document invites a reconsideration of these design priorities.

Another related factor which affects the design of engineering devices is the cost and time of assembly. For all but the simplest

devices, the cost of manufacture far and away outruns the cost of materials. Labor costs associated with manufacture represent a particularly sensitive area in which nonquantitative and irrational elements enter into decision-making processes. For example, it is well-known that plant managers will opt for an automated assembly line over an "old-fashioned" manual assembly line even in cases where it is shown that the manual system is less expensive. Reasons given for this choice include claims of higher quality control with automated systems, or the security that comes from being able to avoid unanticipated labor strikes. Enough subliminal elements of class consciousness lurk in us all that it is doubtful whether any labor-management dispute has ever been settled totally within the calm and quiet dictates of reason. For similar reasons, our ability to evaluate the costs of labor in unfamiliar contexts (e.g., the handicapped community) is perhaps clouded with preconceptions and emotional bias.

It is interesting and instructive to imagine what the products of our technology would look like if we were to remove from the design decision all consideration of the labor costs of assembly, and substitute ease of maintenance in its place. Suppose, for example, that simple mechanisms were constructed in such a way that a paper clip, rubber band, or other common household article, could hold a bolt or shaft in place. A hardened steel shaft used as a wheelchair axle with a soft brass bearing will last forever, provided the user can easily replace the worn out bearing with a new one when needed. We have recently begun development of a quick-replacement bearing assembly that works on a principle similar to an injector razor blade; bearing replacement takes about 3 seconds and may be done by the user while in his wheelchair.

Conventional designs using long-lasting hard bearings rapidly wear the main shaft and promote failure even though the design is said to be highly reliable because it uses hard long-lasting bearings. Systems which require frequent maintenance are even said in some quarters to be "unreliable." We think the opposite is the case; from a human-factors point of view, what is important about reliability is that it minimizes surprises. A design which requires frequent human interaction is less likely to let wear factors get out of hand, and, consequently, would prevent a catastrophic failure from catching one by surprise.

Except for the airline industry, designers and consumers alike seem incapable of thinking very clearly about the role of maintainability in systems reliability. One might think that the do-it-yourself-kit industry has had some motivation to do just this, since the labor costs here, at least from the manufacturer's point of view, are essentially free. However, there is very little indication that anyone is thinking along these lines. Current do-it-yourself kits continue to be designed in a way that minimizes assembly time and maximizes reliability with little or no concession to maintainability. Perhaps this is because to elevate the value of maintainability over reliability is to violate our intuitive suspicion that everyone is too stupid to learn how to fix anything.

While this may be an appropriate attitude for the world at large, it makes sense at least to consider alternative policies for small parts of the world, and in particular for the handicapped who are not severely mentally retarded and can in fact be trained to maintain their own aids. The handicapped often have a lot of free time on their hands and so it seems to make particularly good sense to consider designs for this population that can take advantage of this free labor

and time. This leads us to a consideration of designs that are not only less sophisticated, in the sense that less education is required to understand the basic mechanisms, but also are less complicated, in the sense that they can be assembled by someone with only gross motor control.

IV. FOUR YEARS OF CLASSROOM EXPERIENCE: Origins and Early Efforts

Although CSDL is widely recognized for its research and development work in the space program, and especially for its pioneering work in inertial guidance and control systems, it is not particularly well-known for its work in other areas such as education and human services. It comes as a great surprise to many that the Laboratory is involved in any way with the handicapped. It may be instructive, therefore, to explain how we became involved in this effort.

In previous years, when CSDL was part of the academic faculty at MIT and worked closely with the curriculum planning committee, it was felt that students, having little or no exposure to engineering in high school, were not well-prepared to make the decision to enter a technical school like MIT. Many were confused about what it is that an engineer does. Our initial concern then was to develop a simple course in general engineering that could be taught at the high school level, which might prepare prospective engineering students for what lay before them.

In the fall of 1972, CSDL began an experimental class in introductory engineering, given to second-year high school students from Cambridge and Boston. This class was part of a larger experimental program known as Project CITY (Community Interaction Through Youth, Erna Ballantine, Director). This project was funded by HEW, which requires that a substantial percentage of its funds is to benefit the handicapped directly. This lead us to begin the development of the course with students from the Industrial School for Crippled Children.

Four students attended this class. Three had cerebral palsy and one suffered a congenital spinal injury paralyzing him below the

waist. One student with cerebral palsy was a severely spastic quadriplegic.

Although the class began as a general introduction to engineering science, similar in format to the course given by CSDL staff to MIT freshmen, it soon became clear that the students' own particular set of handicaps represented a much more interesting set of engineering problems than those presented in the usual introductory engineering course. Here was a case in which these engineering problems, if well-presented in class, would be clearly and immediately relevant to the students' own lives.

As a result, the course structure was redesigned, the original goals were reoriented, and the course became known as "Practical Engineering for the Handicapped". The class was continued in the 1973-74 school year with seven students from the Cotting School. (The Industrial School for Crippled Children changed its name to the Cotting School for Handicapped Children in 1973.) In the following years, the size of the class gradually increased to about 10, and teachers in special education (mostly from Boston, although some came from as far as W. Springfield, Mass.) began to sit in and participate.

As we learned more and more about the kinds of devices that were available to the handicapped, we were appalled both by the enormous costs and the way in which the level of sophisication overwhelmed the individual and rendered him more dependent upon a technology that was way over his head. Even now, our perceptions of what is needed for the handicapped are continually changing as we see ever-widening implications in the way our technology fails to meet the deeper needs, not only of the handicapped community, but of the world at large.

Our first concern was with cost. A variety of low-cost aids for the handicapped was designed and built in class. The students

developed, for example, a mechanism whereby crutches could be made to fold to pocket size; they also developed a method for installing snow-tire studs in rubber crutch tips for use on ice and hard snow (see Figure 1). A simple device, consisting of a few relay flip-flops, for decoding voice commands, was designed so that a motorized wheelchair could be voice controlled. Other devices designed in class included a cordless telephone based upon current off-the-shelf citizens band radio components, and a motorized lift to raise a wheelchair from ground level to a loading platform (48 inches). Except for the wheelchair lift, everything was designed to be sold in kit form for less than $150; the wheelchair kit could be packaged to sell for about $300.

One of the more interesting devices developed in class was a machine which allows a spastic to type on an electric typewriter by actuating a few (in this case six) microswitches attached to various parts of his body, specifically those parts that the individual finds easiest to control (see Figure 2). These switches, in various combinations, select and actuate, via a binary decoding network, solenoids which in turn drive keys on an ordinary electric typewriter. This device was designed and built in class at a cost of less than $150. A comparable device that was sold as a ready-made aid for the handicapped would cost between $2000 to $4000.

This device made it possible for the spastic in the class to increase his typing rate by a factor of three. Originally, he could type no faster than one character every 3 seconds. After more experience with this device, it is expected that the student will increase his typing speed by a factor of 10 or more. The success of this approach in this particular case was particularly heartwarming. This spastic has less-than-adequate speech control, so that a

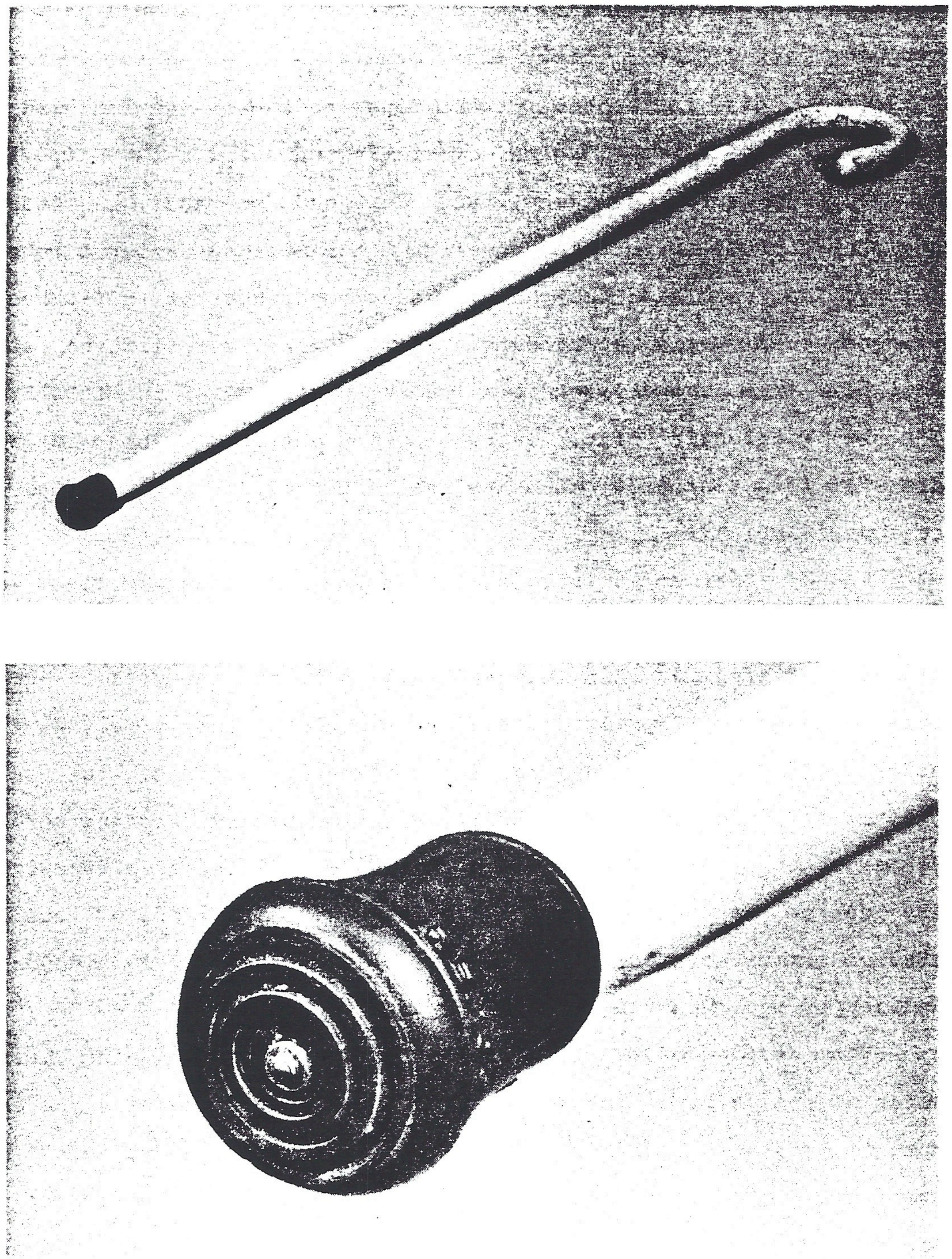


Figure 1. Snow tire stud on crutch/cane tip.

typewriter is his primary vehicle for communication with the rest of the world.

This is one example of a wide range of devices which could be used in a similar way as part of a course in practical engineering for the physically handicapped.

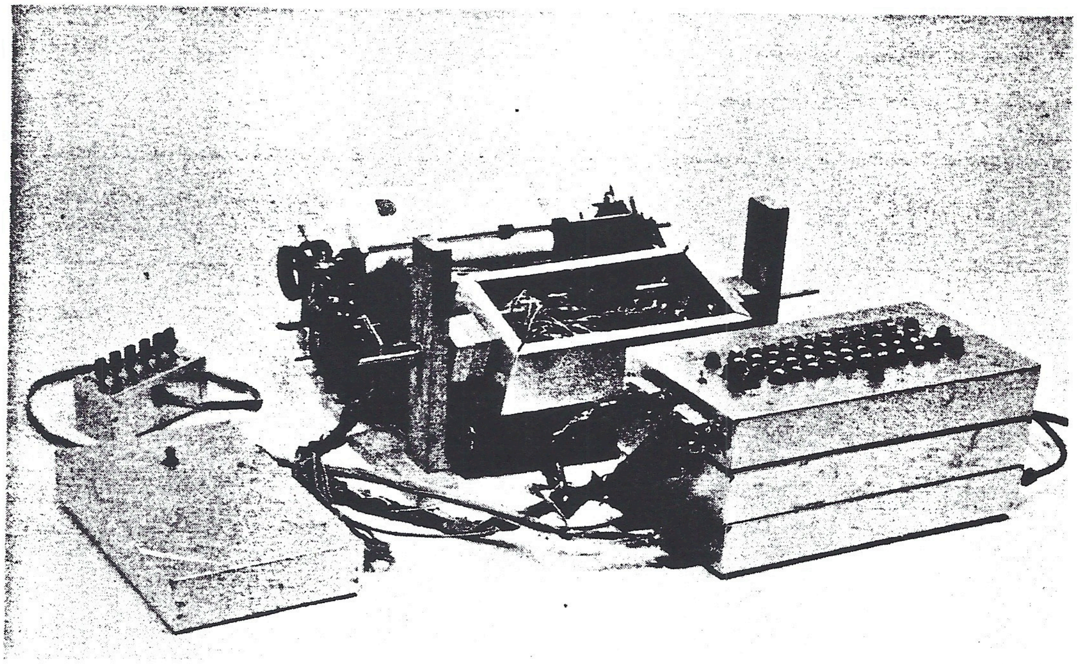


Figure 2. Typewriter driver for spastic.

V. SPECIFIC APPROACHES

1. HARDWARE DEVELOPMENT: Kits, Tools, and Models

The goal of this program is to develop a series of devices which provides hands-on hardware experience for individuals enrolled in a course in practical engineering for the physically handicapped. In addition, it is hoped that at least some of these devices can continue to serve as practical and useful aids for years to come after completion of the course.

The problem of designing aids for the handicapped that can be made in kit form for classroom assembly is a fairly straightforward, although not trivial, problem. In the case of the handicapped, the problems of safety from electrical shock, for example, are most important and are not always easy to solve cheaply. An important strategy, which we have been following, and plan to continue, is to keep things simple and to rely, whenever possible, upon "off-the-shelf" components with simple electrical interfaces that are available in sufficient volume to keep the unit price down.

In cases where cheap and simple components are not readily available, we attempt to devise simple tools to facilitate construction and maintenance of the aids. For example, the solenoids in the electric typewriter driver mentioned above could have been rather expensive (i.e., $2.00 to $3.00 each, and 48 to 50 are required, one for each key). We have developed a technique which makes use of a bobbin winder on an ordinary home sewing machine, so that one can wind coils and assemble solenoids oneself. It turns out to be fairly easy to make or modify coil spools to fit the bobbin shaft (see Figure 3). The central core of commercially made coils is often a flat piece of brass rolled into a cylinder with an open seam; it is therefore easy to expand this spool to fit snugly over the bobbin

shaft. Relays and solenoids wound at home in this way cost only a few cents apiece.

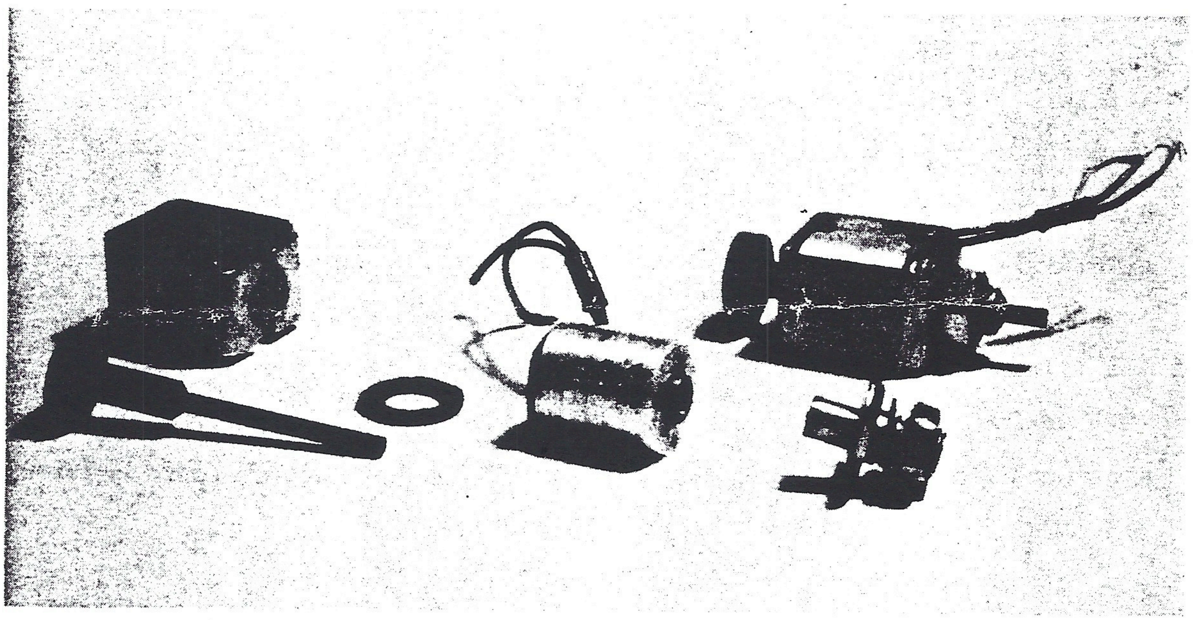


Figure 3. Solenoids used in typewriter driver made on a sewing machine bobbin winder.

Many of the devices in kit form require no special tools for assembly. For example, we are now working on a simple motor-driven wheelchair, and we plan to develop a do-it-yourself hand-control kit for an automobile for someone paralyzed below the waist. Both of these devices can be assembled with ordinary tools.

Although many devices require no special tools, some unquestionably do. Devices for spastics and quadriplegics represent a special class of assembly problems that certainly requires the development of special tools. In exploring solutions to this class of problems, we have been considering several designs for a device similar to a prosthetic training arm. Our strategy here is to treat a quadriplegic as a below-the-elbow amputee.

A training arm is a device that a nurse or physical therapist wears to demonstrate the use of a prosthetic arm and hook to a recent amputee. It sometimes takes the form of a gauntlet, into which a normal hand fits; a hook is attached to the gauntlet and is driven by straps attached to the shoulder or torso in the usual way for prosthetic devices.

Our experience is that many spastics suffer the greatest loss of control in the hands and extremities, and that torso control is often quite good. This fact suggests the possibility that a severely handicapped quadriplegic could regain a substantial amount of control by making use of a training arm whose extremity is actuated by the torso or shoulders. Special tools (e.g., wrenches and soldering irons) could then be adapted for easy operation with a hook.

Existing training arms are undoubtedly too heavy and in general unsuited for this kind of application. We have begun already, with the help of one of our mechanical engineers, who happens to be an amputee with an prosthetic arm, to explore new approaches to this problem. With careful consideration of the problems of stability, damping, and related dynamic control factors, for at least some tasks, it may be possible to achieve almost normal control. In our experiments thus far, we have developed a version of the training arm (see Figure 4) which allows a severely handicapped spastic quadriplegic to pick up a cigarette ash, without crushing it, and place it in an ashtray. This is a feat which no normal person can do, but which is relatively easy for a below-the-elbow amputee with a conventional cable-driven hook.

Although some experimentation has been done in the area of orthoses in past years,it is questionable whether the feasibility of this approach (i.e., linking orthoses with active control systems) has ever been fully demonstrated. At this point, however, we feel that the

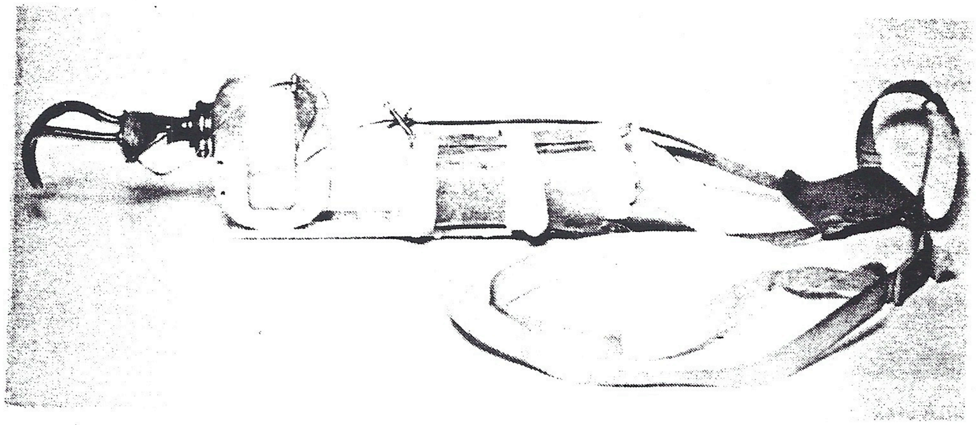


Figure 4a. Training arm: design originated by CSDL Engineer John Oehrle; developed by MIT student Deborah Abbott.

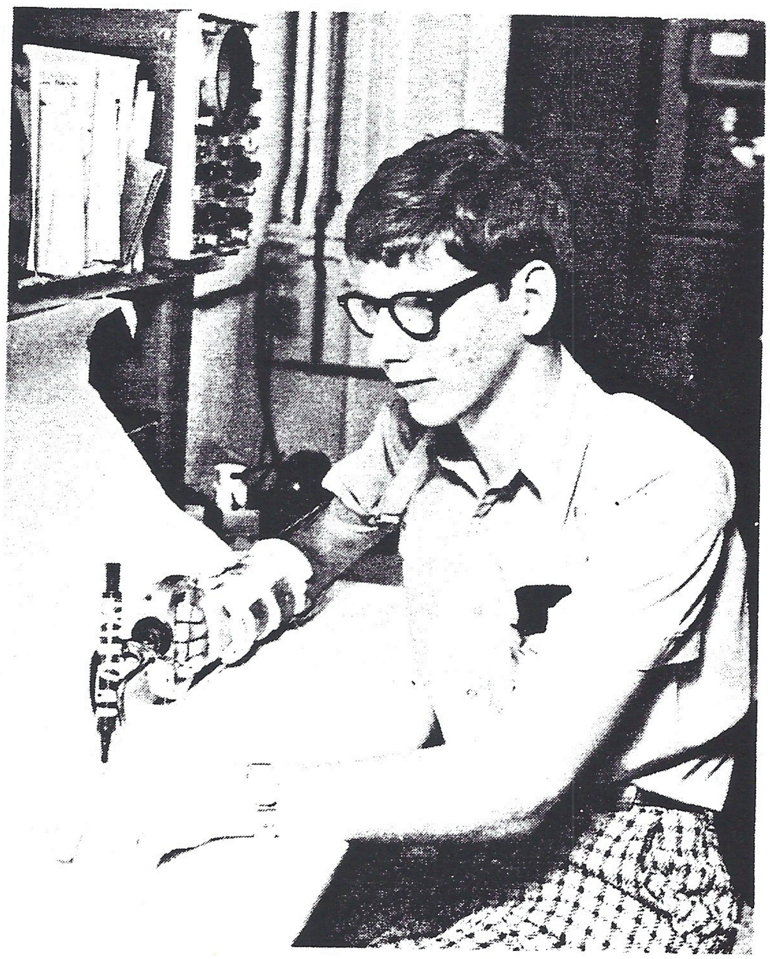


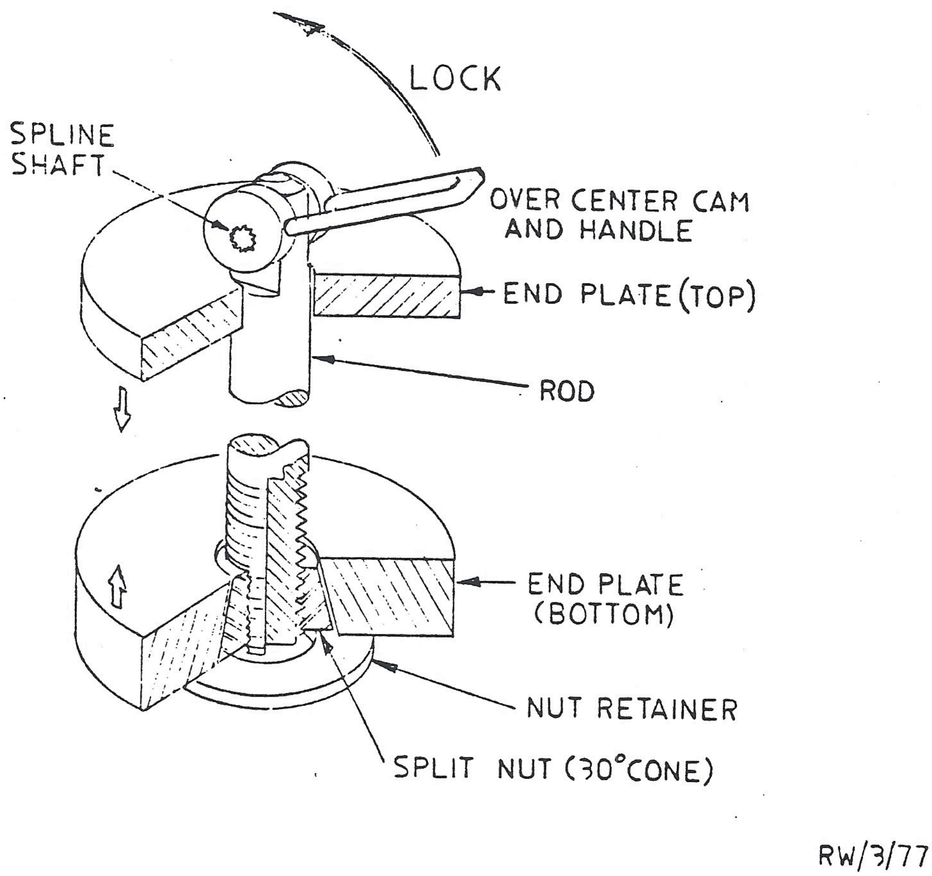
Figure 4b. Thomas Concannon demonstrating adaptation of training arm for spastic.

concept appears promising enough to be worth exploring in some depth. We have discussed this idea with Wally Williams, a prosthetist at Liberty Mutual Insurance Co. in Boston; he thinks the idea is interesting and novel, has made some design suggestions, and in general has encouraged us to pursue it.

Having demonstrated that amputees and some quadriplegics can perform a number of interesting and surprising tasks, such as the handling of cigarette ashes, the problem remains to design devices for the handicapped that capitalize on and exploit this particular kind of control. To this end, we have developed several fastening devices that are intended to replace conventional nuts and bolts. One is a cam-action bolt with a split ring nut that requires no twisting motion to assemble and can easily be handled with the hook on the training arm (see Figure 5).

The design of devices to improve mobility within an urban center and its related architectural barriers is certainly an area that ought to be included in a general engineering curriculum for the handicapped. Practical "hands-on" experience in architectural design, however, is usually not possible in the classroom except through the use of scale models. As a result, we have been exploring the design of modular kits to study the problems, for example, of escalator design, ice-free wheelchair ramps, and a wide range of similar problems.

Many of the devices we already have designed, and which are in the pilot model stage, still need to be evaluated both clinically and mechanically. They need to be submitted to destructive testing to determine lifetimes, replacement and lubrication schedules, and similar maintenance requirements.



Tension on the ring nut is adjusted so that the nut will just pass over the bolt threads when the ring nut is positioned at the wide end of the tapered nut housing, with just enough bite to start the ring nut down the taper as the force is applied on the cam lever. Essentially, the nut is pushed onto the bolt and the action of the cam lever closes down the ring nut locking it on the thread.

Figure 5. Cam action bolt and split ring nut.

2. INSTRUCTIONAL METHODS AND MATERIALS: Conceptual Tools through Hands-on Experience

Each of the various engineering disciplines employs a number of concepts that are common to them all. These are concepts such as 'feedback control loop', 'stability' vs 'instability', 'damping', 'gain', 'homeostatic' vs 'homeokinetic', 'static' vs 'dynamic', 'positive' vs 'negative feedback', 'digital' vs 'analog', and so on. Many of these concepts can be presented to relatively unsophisticated students in the context of direct "hands-on" hardware experience at a workbench. However, experience has also shown that some of the more advanced concepts are more easily learned in the context of computer programming.

Learning about engineering and computer science clearly has some important vocational implications in terms of expanding one's career horizons; but it is important to understand that this effort is more than a simple program of vocational education for the physically handicapped. What is important about engineering and computer science is the way in which it provides a set of very powerful conceptual tools that help transform the way one looks at oneself.

If we believe Alvin Toffler's FUTURE SHOCK, our concepts of 'change', 'process', and 'dynamic control' are among the most difficult concepts that we have to come to terms with at all levels of our life. The concepts of 'time' and 'rate' are usually mastered fairly late in one's intellectual development. Even at the cultural level, it is only recently that we have been able to deal with process and control of complex dynamic systems. The development of the modern electronic computer has played an important role in this development, not because as a labor-saving device, it has freed us to do more important things, but rather because it became a tool to study, simulate, and control, processes so complex that they cannot be represented by mathematical equations alone.

One's own body is an example of a complex dynamic process that cannot be understood in terms of static equations. Computer programming can provide the conceptual tools to deal with one's own body in terms not possible several decades ago. For example, we recently taught a spastic with a serious uncontrolled startle reaction to program in PL1. This enabled us to develop some simple models of muscular train dynamics in which one can learn how time delays can affect damping factors in loosely coupled control systems. This provided the spastic with enough insights into his own motor-control system that he was able to discover postures and ways of standing which loaded up certain elements of the muscle train in a way that successfully damped out much of his previously violent startle reaction. He can now stand on a street corner waiting for a bus and not "jump out of his skin" when someone honks an automobile horn nearby. One should never rule out the possibility of "blind luck" in a single isolated experiment like this, but on the face of it, this approach looks promising enough to be worth continuing.

3. USE OF FILM & VIDEO: Focusing Attention

Teaching engineering can be viewed as distinct from teaching electronics, even though engineering systems may make use of electronics. The understanding of systems in terms of basic building blocks, such as flip-flops, triggers, and delays, is really what is central to engineering; how those components work is the concern of electronics. For example, consider a cordless telephone which allows a paraplegic in a wheelchair to carry a telephone anywhere in his house. It is more important to understand that the cordless system is made up of a transmitter, a receiver, and a telephone coupler, than it is to

understand how a transmitter works in detail. Understanding the basic building blocks of a system like this allows one to see how to create one's own system from readily available components, such as citizen's band transceivers, hand-held walkie-talkies, and acoustical couplers.

For the most part, in our experiments over the past few years, we have been operating on the belief that students can achieve an understanding of systems in terms of their basic building blocks through simple exposure to those systems, which need not involve many deep abstractions or difficult mathematical formulations. Throughout this program, we have been concerned with the problem of making engineering a palatable subject for a wide variety of high school students. It is easy to see how certain individuals could be put off by subjects that appeared highly technical and perhaps over one's head. It is clearly desirable to expose students to examples of engineering systems that will be important in their lives; somehow in this exposure we want them to focus on certain details of structure and organization without having to hit them over the head. When student's minds drift off in a sea of confusion, as everyone's sometimes does, it does not help to say, "Pay attention!".

With this general problem in mind, we began an experiment in the fall of 1976 in which we attempted to expose students to engineering technology indirectly through instruction in photography, film, and video. Taking this tack may have been the most successful thing we have done in the entire course of this program.

Originally, our use of film and video was primarily for documentation, and we assumed that the students would play only a passive role in the filming and taping of our classroom and laboratory experiences. We thought of films as an important vehicle, both for recording classes for later playback to help us evaluate new methods,

and also for training teachers by showing how these new tools and methods are used in a classroom situation. At present, we have some 100 hours of unedited film of our classroom experiments, and we are always generating more footage with the help of the MIT Film Department. We plan to produce at least three 30-minute training and documentary films of this effort.

In previous years, when the students saw the cameras and equipment we were using, of course, invariably, they wanted to shoot some of the scenes themselves. Somehow, the instructor always managed to put them off, although it seemed that everyone was much more interested in film and video than engineering. Finally in the fall of 1976, out of popular demand and a certain quiet desperation, we offered a course in video camera techniques for our Cotting School students; it was a resounding success and regular attendance for the 12 students who participated was the highest it has ever been. Although we had only one Panasonic portable tape deck, all 12 students managed to get some camera time in each class. In this experience, we learned that students absorb a great deal about the machines and processes that they are asked to film. The act of focusing a camera serves to focus one's attention on details of a process in a fairly simple and direct way that is almost painless. This process appears to be independent of any feedback and would probably be effective even if one used a conventional camera with no film in it.

The size of the class is somewhat restricted by the cost and availability of video equipment. We plan, therefore, to continue to explore this technique with photography. For students easily turned off or threatened by engineering classes, photography can provide an interesting inroad to greater understanding. Photography is fun for almost everyone; it can provide some motivation for learning how

cameras work, and that by itself is bound to expose the student to some general engineering principles, which is a major part of what we are trying to do. We expect that giving the students assignments to photograph specific things in the laboratories around MIT will increase their exposure to, and understanding of, a broad range of engineering systems and design. One is tempted to say that these students will be better motivated to take a more conventional engineering course the following year. However, it may be best not to cross that bridge until we come to it; it is possible that similar "indirect" methods will prove better than conventional approaches even in subsequent years.

4. EVALUATION METHODS: "Disinterested Observer"

The development of new classroom techniques and methods in some way implies the development of new methods of evaluation as well. In any genuinely innovative effort, the possibility of failure is always imminent. One is therefore strongly tempted to establish weak criteria for success so that one may be said to succeed no matter what. In addition, the kind of criteria for success one chooses reflect one's level of understanding of the process to be evaluated. That level of understanding is bound to change as one proceeds through a new process. As a result, we propose not to set any explicit criteria for judging the success of this effort until we have been at it for several years.

One of the problems of spelling out clear-cut evaluation methods in a program like this is that there is no simple clear-cut set of skills that should be taught to each individual who participates in the program. If this were true, it would be easy to devise simple tests to see if specific skills were in fact acquired. However, in

this case each handicapped individual has a unique set of problems and limitations. Many, for example, will never be able to assemble their own aids, however simple. For these individuals it will be important to learn how to communicate effectively with others who are able to do the required assembly and maintenance. For example, one may need to know how to explain to a brother or sister how to assemble something; or perhaps one will need to know how to tell someone like a TV repairman how to fix a defective electronic subsystem. Depending upon the level of one's handicap, one may have to do this without drawing any pictures or schematics but by relying simply upon verbal communication, a skill few normal individuals can say they have mastered.

The skills that are taught in this program are rather broad and conceptual. The program is intended to change the level of one's understanding and awareness of technology through exposure to a specific set of rehabilitation engineering problems and suggested solutions. The full impact of this exposure may not be felt for several years. It has been our experience that one needs some time to absorb the experiences that change one's perspective and to translate those experiences into actions that make sense in the specific terms of one's own handicap.

We have experimented with one evaluation method that looks promising enough to pursue in some depth. We approached a local high school for a list of recent school drop-outs (especially those who felt that school was irrelevant). As part of a "work-study program", we asked one of these students to attend one of our classes on a weekly basis, and to keep a journal or diary of all the things that seemed worth commenting upon for whatever reason. This "disinterested observer" is interesting in that we required no particular background

in education or experience with the handicapped. His observations kept the group apprised of basic human and emotional developments which left the rest of the staff free to focus upon technical matters.

It is well-known that outside observers are often helpful in program evaluation. Most instructors, and especially those working with the handicapped, become so emotionally involved with their students that objective evaluation is virtually impossible. An instructor who spends most of his time encouraging, cajolling, and evaluating responses in terms of a student's potential, is not always in a good position to evaluate that student's actual performance. This is one of the reasons good educators often make bad administrators; a good administrator organizes his group or department in terms of the actual performance of his people, not in terms of their potential. Outside professional evaluators of programs like this are often themselves educators, and as a result have their own particular axes to grind and bring their own set of biases to the evaluation process.

What we are trying to do in this program is to respond to the needs of the handicapped on their own terms, and with new perspectives that we hope transcend previous approaches in special education. This "disinterested observer" method appears to offer a broader range of perspectives, so that we can act both as an educator in responding to the student in terms of his potential, and as an administrator in evaluating the effectiveness of tools and educational materials that are developed in this program.

5. CONSUMER EDUCATION: Science Museum Displays

One of the goals of this to program is create a kind of "consumer awareness" on the part of the handicapped that do-it-yourself technology represents a possible solution to their problems. We recently asked one of the largest manufacturers of wheelchairs in the

United States whether they would be willing to produce and market wheelchairs in the form of a do-it-yourself kit. They indicated a willingness to consider the possibility, but pointed out that consumer demand was not sufficient to justify such an effort at this time.

In order to promote consumer demand in this area, we are currently working on a series of displays for museums of science and technology which would show examples of devices, such as wheelchairs, in various stages of assembly. In addition, we plan to show tools, like the training arm mentioned above, and examples of materials, such as cam-action bolts and bayonet-mount fasteners (to replace conventional nuts and bolts), which can be grasped and assembled with the feet, or mouth and tongue, or what have you. The possibility of direct "hands-on" experience, afforded by a science museum environment, could have an enormous impact upon individuals who are now convinced that they could never assemble anything themselves.

Ideally, "live" or manned displays offer the greatest flexibility and maximize the potential for learning through human interaction. We hope to create a set of displays, including a typical workbench at which one of our recently retired electronic technicians spends perhaps 4 hours a day, showing interested visitors how various systems may be assembled, and answering specific questions about present-day technology in the area of rehabilitation engineering. An important virtue of this "live" display method is that it finesses some of the vandalism problems that many museums experience when they try to exhibit anything very complex or sophisticated. It also offers the research and development staff working on this program the opportunity of feedback from a wide variety of potential users and consumers that would otherwise be hard to contact.

VI. LONG-RANGE IMPACT OF THIS PROGRAM

It is often instructive, in evaluating proposals that promise somehow to improve the world or promote the betterment of mankind, to ask the author [redacted] in achieving most of its intended goals. The question really has two components:

1. [redacted]
2. [redacted]

1. INDIVIDUAL IMPACT

A defect of many programs, which promise to improve performance or modify behavior, is that although they are able to show impressive changes on the short run, in the the long run a kind of "Hawthorne effect" sets in, where there is a slow return to former behavior patterns. Motivational background music in a clerical office is a well-documented example of this effect; in the first month, background music usually produces a dramatic improvement in the performance of clerical office staff; after the novelty wears off, there is a slow return to the previous output level. One may well ask whether there is any reason to believe that the initial performance improvements described in this proposal will not also in time suffer a kind of slow return to status quo.

An important key to the process of making permanent changes in an individual's behavior is somehow to transform the way that the individual perceives the world around him and his place in that world. It is our conviction that giving a handicapped individual a tool, with

which he can interact with the world in a new way, is bound to open up new horizons, and this is one of the surest methods of bringing about a change in perception at this level.

Developing engineering skills not only opens up new job possibilities; it also affects one's vocational expectations in more subtle ways because it gives one a deeper insight into a wide variety of mechanisms in the world, and this in turn gives one more control over one's own destiny. For example, in this program a great deal of effort is expended in developing communication skills relating to engineering technology. In the case of the extremely and severely handicapped individual, whose motor skills may be too inadequate to solve even the simplest assembly problems, it is crucial that this person be able at least to explain to a technician, or perhaps just a friend, how to repair a broken electronic aid in a logical and easily comprehended manner. To the extent that one is able to master the technology that one depends upon, along with the attendant communication skills, one has less mobility constraints; one is no longer tied to that rare technician specialist who happens to know how to repair one's crutch, wheelchair, or electronic device. Equally important is the fact that these communication skills prepare one for a wider range of vocational possibilities including administrative positions.

The promotion of less sophisticated technology and "do-it-yourself" kits could have a significant impact on the nonhandicapped individual. Household appliances, for example, are prime candidates for improvement in this area. If dishwashers or washing machines were sold in kit form, and were simple enough to be put together by the average high school graduate, the costs of maintenance and repair would be dramatically reduced. The rising costs

of energy have made us all more aware of the hidden costs of service. If energy costs continue to soar, it is clear that our present way of distributing and servicing the instruments of our technology will have to change.

2a. INSTITUTIONAL IMPACT: Education

An important implication of what has been said thus far is that growth in specialization is counterproductive in the long run. Increases in specialization, which were once perceived as necessary to achieve significant economies of scale, now are seen to have hidden energy costs which may offset those economies of scale. The forces that contributed to accelerated growth in specialization in the past may not, therefore, continue in the near future. This is particularly true of specialization in areas of technology that are widely used, and thus are not at the frontiers of development. As a given technology becomes commonplace, it is natural for that technology to be introduced into the educational process at lower levels. Our present broad-scale dependence upon technology makes it highly desirable to introduce some of the basic principles of engineering and systems design at the high school level. The handicapped community has an even greater dependence upon this technology, which makes it even more important to introduce this technology to its consumers as early in their education as possible, and to link the educational system with research organizations so that ever-developing new technology can get out into the field faster, without promoting overspecialization.

If this program is successful, the style of engineering education at the college level will also change. Engineers are now trained to take into consideration the time and cost of manufacture in evaluating potential designs. These time and cost considerations are typically in

the context of present automation and assembly line techniques. Many good and useful designs are rejected out of hand because of time-consuming assembly requirements. [redacted] The typical handicapped individual often has nothing but free time on his hands.

[redacted] Overspecialization in technology tends to promote highly sophisticated devices, which not only insulate the user from the process he is performing, but also make the user more dependent upon that specialized quasi-elite technology. [redacted]

2b. INSTITUTIONAL IMPACT: Funding Agencies and Hospitals

It is the long-range goal of this program to achieve the same kind of independence at the institutional level that was promised at the individual level. With an economy that appears to be reaching the limits of growth, it is becoming increasingly clear that new programs, which require continuing support from federal or state tax funds, will have minimal chances for survival. This is no less true for new programs that aid the handicapped.

A good program, if it is genuinely worthwhile, can often stand on its own feet, without additional support beyond an initial seeding phase. Our long-range plans include exploring the feasibility of

creating nonprofit organizations that can compete in the commercial marketplace with profit organizations, manufacturing and distributing do-it-yourself kits, and generating funds that can be used to support research and development of aids for the handicapped.

If one takes the energy crisis seriously, and begins to evaluate the energy and mobility requirements, not only of the handicapped, but of the world at large, it becomes increasingly clear that the technician-specialist, who is required by many widely used appliances and devices, is a very costly component in the overall system. The handicapped have always had to face the high cost of mobility. It is interesting that now, with the promise of ever-increasing energy costs that affect everyone, the concerns of the handicapped and the nonhandicapped are beginning to merge.

The return of cottage industry and the development of less energy-intensive production methods is bound to have a decentralizing effect upon a broad range of institutions and funding groups. This, in turn, means that we can expect some erosion in the economies of scale achieved by large centralized institutions. Therefore, it will be extremely important to study the tradeoffs between the economies of scale and the cost of energy in order to identify organizations and institutions that can remain large and centralized and achieve some economy of scale without incurring increased energy costs.

However, the most important effect of a program like this at the institutional level, at least in the author's view, is that it requires a change in the institutions whose primary responsibility is the delivery of rehabilitation technology to the handicapped community. At present, this technology is delivered by physical therapists and prosthetists working within a hospital institution. The danger of this present approach is that the hospital environment can,

and often does, foster an attitude of complete submission on the part of the patient. In this context, the patient makes very few decisions on his own but relies instead upon the suggestions of the medical staff even in such simple matters as the question of which wheelchair to select. In short, the hospital environment sets up attitudes which tend to inhibit one's taking command of one's own destiny. The approach outlined in this proposal suggests that educational institutions should become a primary focal point for the delivery of rehabilitation technology. In the Commonwealth of Massachusetts, Chapter 766 already represents a trend in this direction, although the full impact of this law, with all its implications for educational institutions, will not be understood for some years to come.

VII. EXTENDING THE CONCEPT

1. HOSPITAL STAFF: More Complex Do-It-Yourself Devices

The application of "do-it-yourself" technology could easily be extended to other areas, including hospitals. In a recent visit to a VA hospital, the following situation was observed. In a ward devoted primarily to cases with severe and almost total paralysis, there was a large number of devices known as "environmental control units". Many of these were quite complicated and technically very interesting; they allowed, for example, an individual to turn on and off fans and lights, change the channel on the television set, call a nurse, and so on, simply by blowing or sucking on a tube. It was also observed that nearly half of these devices were, at least at that moment, inoperative, because, as it was explained, the poor little overworked technician, a recent MIT graduate in electrical engineering, who lived in a small room in the basement tenderly referred to as the "broom closet", and whose responsibility it was to repair devices like these all through the hospital, was about 2 weeks behind with a backlog of similar work requests. A brief word with the man in the broom closet revealed that many of the repair tasks include such simple remedies as replacing a fuse or a light bulb, or screwing on a wire that had come off. In fact most of the work could have been done by the nurse or physical therapist if only they had had the courage to look in back of the cabinet.

The message is obvious. If these devices were available in kit form so the the hospital staff could assemble them, the staff would be in a much better position to do these simple repairs themselves and know when to call for outside expert help. It is interesting that this is a case where the advantages of overspecialization begin to break down because it takes longer to bring in the specialist than it does to make the repair.

The development of do-it-yourself kits for hospital staff should in most respects be easier than developing kits for high school level students. Most members of a hospital staff can be expected to have had at least 2 years of college; occupational and physical therapists typically have had 4 years. This fact should allow a wider latitude for sophistication and complexity of design than would be appropriate for high school students.

2. MENTALLY RETARDED: Vocational Opportunities through Simplified Assembly Procedures

On the other end of the spectrum, it may be possible, with slightly more inventiveness, to extend the concept to satisfy the needs of a mentally retarded individual with less-than-adequate motor control, such as a Downes syndrome case. Workshops for the retarded and handicapped often provide a limited vocational experience in which individuals perform simple tasks, such as sorting and sizing nuts and bolts, bundling wires into cables, and so on. Many of these tasks can be presented as simple games and recast in a way that requires only gross motor control. For example one may imagine a game of tag in which selected individuals run back and forth between two rows of people carrying a reel of wire; it is possible to describe a game in which the successful completion of the game succeeds, for example, in braiding a cable.

The basic engineering challenge here is to redesign manufactured packages and subsystems so that they could be assembled by someone with limited motor control and intelligence. Such an approach might make sense in an area where volume is limited and where it is therefore not economical to tool up for an automated assembly line. Computer display panels represent such an area.

VIII. SPIN-OFFS AND NEW DIRECTIONS

1. PERCEPTUAL DISABILITIES: New Therapies using Video Feedback

In experimenting with devices that the handicapped may assemble by themselves, one has to deal with individuals who have serious hand-eye coordination problems. We have found that certain physically handicapped individuals, especially those with cerebral palsy (involving severe motor neuron damage) exhibit not only motor-control problems, as one might well expect, but also sometimes exhibit unusual and subtle perceptual problems that are difficult to describe and even harder to explain, particularly in cases where the afferent pathways appear intact. On the face of it, this may seem paradoxical; one naturally thinks of perceptual disabilities in terms of a breakdown of the input rather than the output, or motor-control, end of the system.

A possible explanation, at least in general terms, based upon research by Richard Held and his collegues at the MIT Psychology Department(1)*, is that normal development of perception depends to some extent upon a good kinesthetic sense and adequate motor-feedback pathways. It is often these motor-feedback pathways that are lacking in individuals with severe physical handicaps.

What follows is an attempt to pursue a line of reasoning, admittedly based upon a very limited but nevertheless positive experience, suggesting that a video system (a television camera and monitor) represents a possible alternative feedback pathway that may help establish the necessary conditions for normal perceptual development in individuals with severe motor disabilities.

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* Parenthetical numbers refer to items in Section X, NOTES AND REFERENCES.

In experimenting with new approaches to the problem of self-help for the physically handicapped, this effort has been concerned with the development of educational materials and methods for training the handicapped to do some of their own engineering and design. A pilot class for handicapped students was initiated to serve both as a "test bed" for curriculum development, and as a basis for training films for prospective teachers in special education.

As the pilot class in practical engineering for the physically handicapped was being documented, some of the students in the class took an interest in the video equipment we were using. Without really expecting very much by way of results, we let a few of them shoot some of the scenes we had planned to incorporate in a tape which was to be used as a training vehicle for prospective high school teachers.

What was particularly interesting and exciting about this experience was that it seemed as though the act of focusing and framing scenes through a camera, with instant feedback on the monitor, began to change the way the students perceived the world around them. Many individuals became much more active and mobile in front of a camera when they could watch themselves "live" on a monitor. Some noticed things about their gait and posture that they had never noticed before. It is true, of course, that a similar effect is possible using film, but the full effect is lacking without the instant real-time playback made possible by video. For example, one could look at a film that was shot from the back to get a new perspective and learn something about the way one stands and walks, but to be able to see oneself in the act of walking as it is happening makes it much more apparent which particular motor commands are contributing to the gait or posture problem. One can see and correct problems almost instantly.

Having once observed that video could help make some changes in the way people see themselves, gradually we began to wonder whether it could be applied to individuals with perceptual problems to change the way they looked at the world. Some of our students were observed to have interesting, but subtle, perceptual problems. For example, one individual, a spastic with what appeared to be normal vision, exhibited an unusual reading problem; in particular, he had difficulty recognizing paragraph indentations even though he seemed to be able to read all the words, at least when presented singly.

We approached the problem in this way. It has long been observed by artists and photographers that looking at the world through a camera serves to call attention to particular features of a visual scene that one may not normally be aware of; for example, elements of foreground-background structure and size contrast are more noticeable when viewed through a lens. Having reasoned, therefore, that framing scenes through a camera seemed to change one's perceptual process, we asked ourselves what would happen if we let our spastic point a camera at a book and try to read it off the video monitor. Viewing a scene through a hand-held camera in this way is interesting because it involves a feedback pathway that is somewhat different from a simple hand-held through-the-lens viewfinder. The video monitor on a table does not move as on moves the camera, while the viewfinder on the camera does. This uncoupling of the viewed scene from the hand movements produces interesting insights in some individuals.

Although our conclusions here are extremely tentative, until we understand more about this process, it appears that holding a camera and viewing the output of a monitor either makes the spastic's problem disappear or else transforms it into another less obvious one. Apparently, commanding the camera to move vertically presents a visual

stimulus on the monitor that makes it clearer that all the sentences line up evenly under one another except where paragraphs begin. Motor-control problems seemed to have prevented a clear vertical scan of printed material.

This experience seems to offer the prospect of a new and interesting therapeutic technique for individuals with perceptual problems that relate to motor-feedback deficiencies. At this point, it is not clear whether it was the instant feedback on the monitor system or the fact that in framing a scene one looks at that scene differently. In any case, this effect warrants further investigation.

The theoretical background for this approach to perception consists largely of research done in psychology and neurophysiology in the last 2 decades. Within the last decade, several reports(1,2,3) appeared, suggesting that form perception is intimately linked with with motor-feedback functions in a way that was not generally accepted among earlier workers in the field. That is, perception is a function of the efferent as well as the afferent pathways of the nervous system. Constraints in motor activity were shown to inhibit the development of normal pattern recognition in cats and other higher vertebrates.

These experiments suggest that the nervous system encodes and transforms visual scenes in terms of motor-feedback commands. For example, when one looks at a table that is described as "square", one rarely "sees" a square directly; in fact the image that is projected on the back of the retina is more likely to be a rectangle or at least a trapezoid. The ability to transform the given trapezoid into a standard square depends upon one's having learned at some point to lean forward, cock the head, etc., to bring the image "squarely" into view. That one visual scene is transformable into another is not

solved as a problem of abstract spatial coordinate transformation such as matrix inversion in a digital computer; rather it is solved by "remembering" a series of internally felt motor commands that succeed in performing the desired transformation. If one has a paralyzed back or neck, and cannot therefore move forward or cock one's neck reliably in the appropriate way, it is easy to see how such an individual might have subtle perceptual problems.

If this picture is essentially correct, then a hand-held video camera may represent an alternate way of transforming a visual scene in terms of motor-feedback commands required by the central nervous system. For example, an individual with the kind of perceptual problem that results in confusing rectangles and trapezoids may learn to hold a camera over a picture of a square and move his hand around until the square looks "square". This experience allows him to internalize a set of motor commands that successfully transform visual scenes.

Ultimately, the goal of future research in this area will be to determine whether learning to command a camera and seeing the immediate results on a monitor will effectively bypass defective feedback pathways and diminish subtle perceptual problems.

2. A COMPUTER IN THE LOOP: Tracking Eye Movements and Video Communication, Art, and Therapies for Severe Spinal Chord Injuries

a. Introduction

The material in this section was developed in reponse to the needs of those individuals who are almost totally paralyzed by a severe spinal chord injury. The research began as an attempt to outline a system which can provide a vehicle for communication and entertainment for totally paralyzed individuals whose motor activity is limited to simple eye movements.

Although artists have sometimes described the act of viewing a static painting as a "dynamic", or even "interactive", process, very little research has actually been devoted to the study of the dynamics of vision in a genuinely interactive context. Recent developments in computer technology and video instrumentation now make possible at relatively low cost a class of experiments in which the viewer, by means of a computer monitoring eye movements, can actually participate directly in the formation of visual scenes which can be shared by other viewers. This possibility promises not only entirely new dimensions of interactive visual art, but it also opens up possibilities for new kinds of therapies for individuals with perceptual disabilities, and a potential means of communication for individuals so severely handicapped that they can only communicate by simple horizontal eye movements.

Traditionally, the relationship between the artist and the viewer has been described in terms of "active" and "passive" participation, in which the viewer is usually said to have primarily a passive role, even though, to be sure, some active elements are clearly recognizable in the process of aesthetic appreciation.

What follows represents a radical departure from this traditional paradigm. This section outlines a way to explore new forms of visual experience in which the viewer may be said to participate actively and directly in the process of appreciating a visual scene; in fact the viewer may be said to help create the visual scene according to the particular way his eyes scan a portion of that scene.

Imagine a device like a TV screen, or cathode-ray tube (CRT), which is viewed by someone while a television camera closely monitors his eye movements. A computer determines what part of the visual scene is being observed in any given instant, and gives a command to modify the scene on the CRT accordingly. Any number of rules for modifying the scene are possible. For example, in the simplest case, the CRT may trace out a series of line segments representing the time history of points of focus on the CRT screen. This, in effect, allows one to create a line drawing with one's eyes.

Other possibilities include modifying an existing scene according to where, or how long, one looked at a particular spot in the scene. For example, if one is gazing at a picture of a face on the CRT screen, the computer may cause the face to wink or smile, and thus drive the eye, and presumably the viewer's attention, to another part of the scene. Compared with conventional visual art, the possibilities here are virtually endless.

All of the materials and hardware required for this system are currently available in the commercial marketplace at reasonable prices. Basic television cameras and monitors are available for about \$100 each. Recent developments in microprocessors have made available computers of sufficient capacity for this task in the price range of \$1000 to \$1500. Adapters are widely available that allow any 35mm lens to be attached to a video camera; a special close-up, or "macro", lens is required fill the camera's field of view with the whole eye.

A simple method for determining eye position, developed by Macworth and others(4), is to follow the relative position of a spot of light reflected off the eyeball. The fact that an eyeball is not spherical, but rather an ellipsoid, makes it possible to track eye movements by tracking changes in the position of the reflected spot.

A highly intense spot of light may be reflected off the side of the eyeball, at such an angle that the light does not strike the retina, with the result that the viewer need not be uncomfortable or even aware of the spot.

A TV raster represents an array of roughly 500 x 500 points of light; each point is capable of 12 to 16 levels of grey. Each spot is refreshed 30 times per second. This represents much more information than is actually necessary. It is estimated that a much coarser scan, something on the order of 200 x 200, or 40,000 points, will allow the computer to scan the field looking for the spot of light approximately four or five times per second. At this rate, the computer processes 200,000 points per second, spending an average of 4 or 5 microseconds per point. This represents a "worst-case" situation in which the computer had to rescan the field each time. If the computer can command the camera beam to begin its scan in the vicinity of the most recent spot, the computer may be allowed to spend much more time processing each spot. An even simpler solution is to build a small special-purpose device that simply records the x/y position of the spot 30 times per second.

b. Exploring New Dimensions in Visual Art

An artist spends many years learning the sensory-motor skills necessary to reproduce faithfully his inner visions. After this initial training and acquisition of aesthetic sensibility, many

artists hope that the same training will become second nature and recede into the subconscious or be forgotten entirely in favor of spontaneous expression. Matisse said that he spent 50 years forgetting how to draw.

This hope is always dependent on the artist's manual skills, and the transformations inherent in the processes are of course quite pleasing and expressive. But the concept and the physical reality of the work are nearly always distinct entities, and often the end product is strangely removed from the original vision, if not actually disappointing. There are so many links and exchanges between the vision and the manifestation that the latter is often an abstract and quite different image from the one present "in the mind's eye".

During this process, although the eyes are the intermediary between the mind and the mechanisms of expression (without which the whole process would be entirely impossible), they never generate the image directly. This document suggests that it is possible to develop a system by which the eyes themselves produce an image. In addition to the scientific and medical (therapeutic) benefits (see below) of this system, the potential for artistic exploration is very rich indeed. Possibly for the first time, the artist will possess the means to eliminate at least part of the sensory-motor linkage, and have a more immediate and less constrained method of realizing concepts, utilizing on a strange new level the most valuable of artistic instruments - the eye.

The artist can discover how the visualization process really "looks", at least temporarily without interference from old sensory-motor skills, while still possessing all aesthetic capabilities. By monitoring, recording, saving, and displaying almost instantly the tiny movements of the eyes as they "see" an image, all

the richness and intensity of the visual process may be experienced in perhaps its purest form.

Of course, these "images" may at first be incoherent. The artist will have to be receptive to all the potentially different elements of this new "medium". With experience, a type of training may occur, but hopefully not in the same manner as the sensory-motor skills are acquired. There is a potential for an entirely new type of conceptualization, realization, direction, and adjustment that is incredibly exciting not only for artists but for anyone interested in the visual process(5).

c. Communication for Totally Paralyzed Individuals

Veteran's hospitals and spinal injury wards are often confronted with the problem of treating individuals who are permanently paralyzed below the neck, and who therefore have nothing to look forward to but a lifetime on their back with little or no recreation or communication with other individuals. Eye movement and mouth gestures may be the only motor activities that are possible with this type of disability. Speech is usually impossible or unreliable because impaired throat and lung control inhibit sufficient air flow through the larnyx to produce sound.

Almost any device that monitors eye movement could become the basis for a system of communication, not only with other individuals to maintain some level of socialization, but also with machines which can provide a vehicle for recreation. Communication with machines, particularly interactive machines such as computers, opens up a set of interesting recreational possibilities that has not been widely appreciated or utilized. For example, it is easy to see how one may command a computer to make particular chess moves by one's eye movements.

Not only can a device that monitors eye movements provide inputs to a number of common aids for the paralyzed, such as automatic page turners and environmental control units, it can also establish communication with the so-called "intelligent machines", devices that play checkers and chess, compose letters, and make phone calls.

d. Therapy for Perceptual Disabilities

One of the earliest applications of computer-monitored eye movements was the study of individuals with reading problems(4). In these early studies, the computer was used primarily as an input data processor; the primary concern was with monitoring natural or unrestrained eye movements as a painting or a printed page was scanned. This proposal suggests that additional therapeutic benefits may accrue from the possibility of actually "driving" the eyes across a visual scene by making subtle changes in that visual scene as the eyes move across it. For example, one can imagine training sessions designed to promote or encourage better (i.e., smoother or less random) eye-movement patterns as one reads a printed page.

IX. QUESTIONS OF LAW AND PUBLIC POLICY

1. Manufacturer Liabilities

[redacted]
This program is no exception.

The first hint that we were bucking the tides of public policy came as the result of a series of letters we wrote to a number of manufacturers, some of whom made and distributed do-it-yourself electronic kits, and some of whom specialized in conventional aids for the handicapped. We asked these companies whether they would be interested in being licensed to make and distribute the do-it-yourself kits for the handicapped which we have been developing and testing over the past few years. The concensus of lawyers representing these manufacturers that responded was essentially that "[redacted]." Why? Because of uninsurable liabilities on the part of the manufacturer.

It can be explained in this way. If Heath Kit Co., for example, were to sell a color television kit to a spastic quadriplegic who, in turn, electrocutes himself in the process of putting the set together, the company can claim that it is free of liability because this set was neither marketed nor intended to be assembled by special-needs individuals. On the other hand, if the company were to market a device specifically designed for the handicapped, then it assumes some responsibility in meeting the requirements of these special-needs cases. If a handicapped person assembles a wheelchair kit incorrectly,

and then hurts himself because a wheel fell off, the manufacturer is presumed to share some liability. The manufacturer clearly has the responsibility to prepare the materials and directions so that accidents of this sort are minimized. Manufacturers generally are able to buy insurance that covers them against suits resulting from this kind of liability.

[redacted] Apparently, the fact that these kits are intended (initially, at least) to be assembled in a classroom under the close supervision of an experienced instructor does not completely absolve the manufacturer from some basic liabilities, even in areas that may be largely out of his control. Manufacturers may be held liable for mistakes made by the person assembling the kit. (If this sounds absurd, don't worry; read on - it get's worse.)

2. Recent Trends in Consumer Advocacy

In search of avenues to circumvent this obstacle, we began to recruit students from the MIT Sloan School who were interested in law and public policy; we offered them the problem, as a term project, of writing a preliminary "strawman" bill which might be sponsored in principle by an appropriate senator or congressman. The substance of the bill would be the creation of legal provisions allowing the Federal Government to underwrite, on a trial basis for some specific period of time, a company so that it could make and distribute do-it-yourself aids for the handicapped.

In addition, in 1976 we began a limited campaign to increase consumer awareness in this area. This included speaking engagements to groups of handicapped individuals and associations representing their interests. It was felt that their endorsement of our program was important if we were to succeed in what was shaping up to be a major battle.

Generally speaking, t[redacted]this is being written, we are recieving an average of just over one call per day from someone in the New England area asking us to help them in some way, either by designing an aid for them, or by helping them set up a similar program in their area. It is worth noting that an enthusiastic response from a group so clearly in need of help is not a surprising phenomenon; anyone who even looks like he might help the handicapped gets inundated with requests if he is not careful. Thus, i[redacted].

Moments such as this promote a certain amount of soul-searching, raise questions of self-doubt in even the most intrepid, and make one wonder whether it is worth it to continue to beat one's paddle against the rising tide of what can only be described as "consumer rights madness". We live in an age of malpractice and class action suits that has all consumers, including the handicapped, riding on a wave of high retribution.

For the past several years, a class action suit against a major manufacturer of wheelchairs has mobilized the forces of a considerable number of handicapped consumers. The claim of the consumer advocacy lawyers arguing on behalf of the handicapped is that wheelchairs have grown more unreliable, while prices have increased enormously. Several individuals have been seriously hurt in wheelchair failures. As a result of consumer advocacy claims such as this, lawmakers and policy makers , wishing to appear responsive to the needs of the handicapped, have begun to push for more stringent laws protecting the handicapped from what they perceive to be irresponsible manufacturing practices. [redacted]

3. Reliability and the Law

It is now widely felt that the law is the only way to ensure reliability in the instruments of our technology upon which we have grown so dependent. This is an understandable attitude, but one which I believe will not stand the test of time. The problem is that reliability is a very complex matter, and different people mean different things by it, depending upon their level of understanding. For some, it means that you never have to fix anything. For others, it means that the time between failures is relatively long. For still others, it means that failures are few but predictable. Too simple an interpretation of "reliability" will drive the cost of wheelchairs up and that means ultimately that fewer handicapped will be able to afford them. But what is more important is that they will still hurt people when they break down because those breakdowns will be even less anticipated than they are now.

Current trends in consumer law seem based upon the assumption that the consumer is not only stupid but irresponsible. He cannot even

be expected to delegate the responsibility of maintenance to someone else. It is as though he should just be able to forget about maintenance and reliability; somehow the hardware is just supposed to take care of itself.

In addition to laws protecting the general consumer, there are a number of traditional practices, quasi-laws and codes of ethics, which deal with health care delivery, that also affect the way the handicapped are treated. For example, there is a longstanding tradition that no one, not even doctors, treat themselves. [redacted]

I am not certain that revoking old laws and writing new ones will really help this kind of problem. It can be argued that it is not the laws, but their interpretation that needs changing. Clearly there should be laws and guidelines that prevent irresponsibility on the part of the manufacturer; but somehow consumers should have to be responsible as well.

Each element in the total system has to carry its own weight or else the total system will ultimately breakdown. We are now witnessing such a breakdown in our health care system with soaring medical costs; recent graduates of medical schools are prevented from practicing medicine because they cannot afford the skyrocketing premium costs of malpractice insurance. It is clear that medical patients of all kinds, and not just the handicapped, will have to take more responsibility in the delivery of their own health care.

In this time of rapid technological change, in which everyone feels frustrated, many feel alienated, and some feel "ripped-off", the

class action suit promises quick relief. "Sue the Bastards" is now a common bumper sticker. It is as though we have all gone crazy, particularly with respect to the handicapped.

It is a craziness, born of good intentions, but brought on by a carelessness and inattention to detail, that stems ultimately from the fact that the handicapped are not themselves directly involved in consumer policy decision making. [redacted] "Give them a world on a silver platter... and they'll come home wagging their tails behind them."

X. NOTES AND REFERENCES

(1) Held, R., and A. Hein , "Movement-Produced Stimulation in the Development of Visually-Guided Behavior", Journal of Comparative Physiology and Psychology, vol 56, pp 872-876.

(2) Hein, A., "Recovering Spatial Motor-Coordination after Visual Cortex Lesion", Perception and its Disorders, D.A. Hamburg (ed.), Williams and Wilkins, Baltimore, 1970.

(3) Hein, A., "Development and Segmentation of Visually Controlled Movement by Selective Exposure during Rearing", Journal of Comparative Physiology and Psychology, vol 73, pp 181-187.

(4) For a good summary of current techniques, see: L. Young and D. Sheena, "Eye-Movement Measurement Techniques", American Psychologist, March 1975.

(5) This section was authored by Derith Glover, MIT graduate student at the MIT Center for Advanced Visual Studies.

(6) This section is scheduled to be presented as a paper at the Fourth Annual Conference on Systems and Devices for the Disabled in Seattle, Wash., June 3, 1977. Selected portions of Sections I through IV of this report were presented at the Third Annual Conference in Boston, Mass., in June 1976

APPENDIX A

CATALOGUE ENTRY:

The Charles Stark Draper Laboratory, Inc., Cambridge 02139; Practical Engineering for the Physically Handicapped, 40 weeks, Jan - Dec 11th and 12th grades. Includes research participation and work study during summer. Richard E. Warren, Director of Rehabilitation Engineering.

LIST OF STUDENT PARTICIPANTS:

(a) Cotting School Engineering Class:

Joanne Breen	Dennis McCarthy
Thomas Cassidy	Joan Manning
Thomas Concannon	James Marfoli
Mary Fitzgerald	Charles Murray
Thomas Flaven	Brian Shea
James Gill	Barry Stafford
Gerald Linehan	Pat Stanton
Peter White	

(b) Cotting School Video Class:

Marilyn Diamond	Jeanne Mackey
Valry Fleetwood	Mary Murtaugh
Winsome Frazer	Cheryl Ravalli
Margaret Gillis	Christine Russo
Bevery Johnson	Marilyn Shaughnessy
Terry Lacroix	Margaret Zaremski

(c) MIT Student Researchers and Teaching Aids:

Deborah Abbott	Mark Bressler
Derith Glover (thesis)	Steve Holland

APPENDIX B

FACILITY DESCRIPTION

1. The Charles Stark Draper Laboratory, Inc. (CSDL)

CSDL, formerly known as the MIT Instrumentation Laboratory, was officially divested from the academic wing of the Massachusetts Institute of Technology in 1973. At present it is still considered part of the Institute in the sense that it offers courses to MIT students, supervises thesis projects, and provides a substantial source of operating funds for the Institute, although it has its own charter as a separate non-profit educational and research institution.

CSDL is widely known as a leader in the field of small special-purpose control systems. Although best known for the design and development of the Apollo spacecraft guidance system, CSDL also has a wide and substantial experience in biomedical areas, including the development of an automated clinical chemistry system, a bedside cardiovascular system monitor, and pacemaker controllers.

2. The Cotting School for Handicapped Children

The Cotting School for Handicapped Children is a privately supported tuition-free nonsectarian day school for physically or medically handicapped, mentally normal boys and girls from the first grade through high school. It is located in Boston on St. Botolph Street, opposite the Boston Arena.

A wide variey of handicaps is represented in the enrollment, including amputations, asthma, acute injuries, birth defects, cardiac disease, cerebral palsy, diabetes, epilepsy, hemophilia, polio, rheumatoid arthritis, scoliosis, spina bifida, muscular dystrophy, and others.

Until 1973, the school was known as the Industrial School for Crippled Children. Although its former name suggests a trade school, it has always been in fact a regular educational institution providing 12 grades of school work comparable with any public school. Classes are typically small, with a maximum student-teacher ratio of 15 to 1.

The Boston Globe Wednesday, August 22, 1973

Draper Laboratory helps handicapped to design devices to help themselves

By Phyllis Coons
Globe Staff

Pacemakers driving crippled arms and legs? Crutches which fold into pocket sized packages?

Both are feasible in the near future with the development of miniature gyroscopes and accelerometers, says Dick Warren, a bio-medical computer engineer at the Draper Laboratory in Cambridge.

But Draper scientists are not going into business to design aids for the handicapped, even though it is a new spinoff from guided missile navigation.

Goals of research scientists are to show teenagers how engineers solve problems and what part math, physics, chemistry and history play in the process.

Draper, a former instrumentation laboratory, became a division of MIT three years ago. MIT divested itself of the research facility in July to avoid partnership with the Defense Dept., which supports it. But MIT has asked Draper's scientists to carry on with its seminars for college and graduate students and continue to offer supervision of thesis projects.

Teaching teenagers is a new venture for Draper volunteers. Three of their most enthusiastic students are from the Industrial School for Crippled Children in Boston.

Most aids for the handicapped increase their isolation from the world around them, says Warren. Gadgets such as electric wheelchairs are like Cadillacs. They protect people from problems. Simpler aids which the handicapped can help to design and maintain make them feel more independent.

To Tom Concannon, 16, for whom cerebral palsy makes every step a gamble that he might fall, making tools which enable him to type is like magic. He and two classmates at the Industrial School for Crippled Children, Brian Shea and Peter White, started taking Warren's science course in January. When summer came, they "refused to leave the laboratory" says Porter.

Tom and Warren have worked together to design switches so that muscles in Tom's elbows and heels can supply direction and power which his fingers cannot.

When Tom pushes levers with his good muscles, a box with glass knobs simulating the keys of a typewriter lights up certain letters.

Wires attached to the box operate metal pins which press keys on the typewriter.

Before Warren volunteered to teach Tom and his classmates, the idea of taking taxies by themselves to Cambridge seemed to them an invitation to accidents.

Within a few months of classes at the Draper Lab, Tom and Brian and Peter were helping to design tools so that they could manipulate soldering irons, although Tom is unable to hold a pencil.

Teaching handicapped students how to design their own tools (bio-medical engineering) is only one of the programs at Draper for teenagers. Hank Brainerd, who is a railroad buff as well as a scientist, has taken them on trips to analyze transportation systems. Bob Tanguay toured them around the Deep Submergence Rescue Facility at Draper. Al Freeman taught them about gyroscopes.

The idea of taking on 16-year-olds grew out of a seminar for college freshmen started at Draper by Phil Bowditch (a great great grandson of Nathaniel Bowditch, author of "The Practical Navigator") gave freshmen a bird's eye view of science in 14 weeks.

Teaching teenagers was based on the seminar idea. Ed Porter, who heads Draper's Communications and Education Dept., volunteered to teach a capsule version of Bowditch's course for one week last year at Arlington Catholic High School, where his son was a student.

Handicapped youngsters were next for two reasons — Dick Warren and Preston "Al" Pardee, new director of CITY (Community Interaction Through Youth).

Warren, who majored in philosophy, says his interest in bio-medicine "comes naturally because I am the only living Warren in my family who is not a doctor."

TYPEWRITER FOR HANDICAPPED — Handicapped youths design own aids at Draper Laboratory with advice from Richard Warren of lab. From left are Peter White, Brian Shea and Tom Concannon, collaborators on project.